Beyond just floodwater

Flooding, already the largest hazard facing humankind, is becoming more frequent and affecting more people. Adapting to flooding must consider more than just water, to encapsulate the effects of sediment movement, reimagine flooding through a sociogeomorphic lens and expand approaches to knowing about floods.

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The major floods of 2021 and 2022 – across NW Europe, China, India, South Sudan, Western Canada and South Africa – have brought into focus the devastating impacts of river flooding on people and the environment. Already the deadliest and most costly 'natural' hazard, impacting hundreds of millions of people each year and causing global annual financial losses exceeding US$65 billion[1], river flooding is a growing threat. This is a result of anthropogenic climate change increasing the frequency and magnitude of rainfall extremes, growing populations, and rapid economic development in flood-prone areas[2]. In the wake of floods, media, scientific and policy deliberations often focus on the causative weather events, and their relation to climate change[3], or on the efficacy of approaches to predicting, managing and governing flood inundation[2]. Although such discourse is essential, two critical aspects of riverine flooding are often neglected. Firstly, floods are conceptualized frequently as simply flows of water, neglecting the importance of sediment[4] and thus the long-term role of floods as builders and modifiers of fluvial landscapes. Secondly, rivers and their floodplains must be viewed as more-than-physical phenomena, which demands a broad rethinking of human (individual, community and institutional) relationships to rivers as part of hazard mitigation and adaptation.

Landscape change, sediment and hazards

River channels are not just conduits for water flow. The sediment they transport is fundamental to shaping alluvial channels, influencing channel stability and determining flood capacity[4]. Rivers come alive during floods and sediment transport is intrinsic to this transformation. As an example, higher sediment fluxes are anticipated in High Mountain Asia because of increased flow discharges generated through global warming[5]. Such increased sediment flux may also generate channel change. The catastrophic 2010 Indus River flood, which killed more than 2000 and displaced *c*. 20M people, exemplifies how large-scale, sediment-induced change must be better integrated into analyses of riverine flood risk. Although the Indus floods began with intense, but not unprecedented, rainfall in the upper river basin, the main flooding was caused by a shift in the course of the river channels. This river avulsion was primed by sedimentation being constrained within artificial levees that were ultimately breached[6]. In the Indus River, as with river deltas where accretion is being encouraged to help offset rising sea-level, sediment management through flow diversions (e.g., engineered levee breaches) must become fundamental to developing more sustainable flood mitigation strategies[6]. Techniques such as these have roots in indigenous approaches to living with rivers that were practiced well before western technocentric influences[7,8]. In addition, the potential significance of vegetation as bioengineers may be important to assess, such as in considerations of vegetation removal enhancing bank and channel instability. Knowledge of sediment dispersal and its impact on geomorphic change, and centrally the humans that inhabit these landscapes, provides an imperative for a socio-geomorphic perspective to enable a more sustainable approach to living with floods.

Particles, pollutants and floods

In addition to hazards linked to landscape change, historically contaminated sediments remobilized during floods of various magnitude can raise significant issues for human health[9,10]. Although the supply of sediment and nutrients to floodplains is vital for their ecological functioning, erosion of contaminated sediments may lead to long-lasting problems through remobilization of pollutants such as polychlorinated biphenyls (PCBs), polychlorinated dibenzo-*p*-dioxins (PCDD's) and radionuclides[9,10]. Such contaminants may pose risks to human and animal health through a range of carcinogenic, neurotoxic, genotoxic and immunotoxic effects[10]. For example, the levels of PCB's and PCDD's in beef cattle have been found to be greater in farms with flood-prone fields[11], with contaminants sourced from legacy pollutants linked to previous industrialization and recent combustion activities. Radionuclides from former uranium-mining sites were mobilized during the exceptional 2002 Elbe River floods in Germany and the Czech Republic[9]. Microplastics are another pollutant of emerging concern in riverine corridors. It appears that most microplastics are retained in river sediments[12], and their mobilization is increased greatly due to riverbed scour during large floods[13]. Consequently, amplified flooding may generate substantial increases in the yield of riverine microplastics. Observational data and modelling[10] reveal the role of suspended sediment as a host for particulate-bound contaminants, the direct mobilization of particulate pollutants, and how contaminant yields relate to economic development and urbanization. There is thus a need to map the spatial distribution of contaminated legacy sediments and monitor their potential remobilization as affected by changing flood frequency and magnitude. This must assess flood magnitude to determine whether contaminant release is a slow, continuous threat, or linked to extreme flood events. Flood hazard impact assessments cannot, therefore, be based solely on inundation risk, but must incorporate considerations of sediment and contaminant type, mobility, flux and fate.

Riverine landscapes and human health

Flooding and sediment pose multifarious hazards to human health, including drowning, direct injury, poisoning, infection, hypothermia and chronic disease, although psychological morbidity (including depression, anxiety, and post-traumatic stress disorder) may form the largest burden of disease following a flood[14]. Such health vulnerabilities are also amplified through racial, economic and habitation inequalities, as highlighted by studies[15] revealing the role of structural racism and social influences on child health as affected by climate change, including the effects of flooding.

Consideration of floods solely through mapping of inundation onto socio-demographic characteristics may thus miss the heterogeneous effects of floods on human health and wellbeing. This shortcoming demands coupling of hydrological and sediment dispersal modelling with social and healthcare estimations of vulnerability in terms of disease burden and mental wellbeing. To achieve success, such assessments must be transdisciplinary (for example, including hydrology, geomorphology, healthcare, ecotoxicology, civil and chemical engineering, sociology, economics and GIS) and integrally involve indigenous knowledge, community involvement and direction. Indeed, incorporation of the impacts of floods, and nature-based solutions for river flood risk mitigation, is inherent within many of the UN's Sustainable Development Goals (SDGs)[16]. Real progress towards achieving the SDGs will be undermined unless the impacts on human health are quantified more fully with respect to the geomorphic and healthcare landscapes on which they are situated. Accounting for sediment is integral to this progress.

Reimagining floods through a sociogeomorphic lens

Hydrological analyses often imagine flooding primarily as a connected, complex, physical system, with problems for which there are technical and managerial fixes[17] – the water machine. Yet rivers are integrated and entwined socio-natural systems, in which sediment is an essential part. That the presence and transport of sediment is 'entwined with social needs, values and activities' imbues it with a 'social life' that must be viewed in its historical context[4]. Rivers can be conceived to possess particular attributes and functions within a community, region or nation, which negotiate their relationship with waterways. Controlling, constraining, and confining rivers can be part of that relationship, and may be disturbed by events such as large floods[8], stimulating collective re-thinking of what a river is. After extreme floods, individuals, communities and institutions often articulate that they had no idea that the river was capable of these effects, including sediment erosion and deposition, such as 'muddy floods' from agricultural fields[18]. In the consequent decision-making events to plan future flood response, socio-political factors, cultural influences and communal expectations become as significant as the physical processes[19]. Indeed, the loose organization of people to secure a world together ('communitas') often occurs after major disasters[20]. Understanding how such organization happens may be as important as considerations of vulnerability and resilience.

Consideration of flooding as part of the functioning of a socio-natural system leads to the idea that flooding is a wicked problem for which there is no ultimate technical fix to eliminate flood damage. The hubris of the technical-only fix reflects a failure to envisage the full extent and inter-connectedness of the socio-natural system, as well as the pervasive social influence on our conception of - and relationship to - rivers and flooding[8]. When viewed through this lens, flooding and sediment dispersal can be conceived as part of a continuous, connected, series of events, both hydrological and socio-political, stretching back through time and into the future through which the system develops and changes. Such historical connections between rivers and society[4] provide the prerequisite context for understanding how sediment and geomorphology have shaped human settlement and how anthropogenic imprints influence landscape and societal change. The two are inextricably linked. It is thus essential to account for the ways that humans inhabit landscapes, the socio-politics of flooding, and the material power and agency of rivers, including the role of sediment, river dynamics and geomorphic change. The dominance of technocentric approaches to river dynamics closes off more profound understanding of how society and community shape vulnerability[4]. At a deeper level, flooding, and associated sediment dynamics, are examples of the need to examine the political economy and political ecology of socio-natural transformations more fully[21], as well as the use of particular forms of knowledge[7] to better inform the dominant mode of thinking in resolving flood crises.

Adopting more holistic approaches will also likely stimulate thinking concerning the essential nature of a watershed or hydrological system. Dominant technocentric modes of current thought lean towards a quasi-deterministic, causally-connected, objectively quantifiable, predictable, controllable, and primarily-physical system[22]. These are connected to a kind of presentism, in which the history and future of the river are disconnected from the technical solution. The extent to which this viewpoint is viable determines the extent to which we can conceive of, and respond to, flooding. A clearer connection as to how rivers, and views of rivers, change over time is an essential aspect of the need to re-think watersheds. One extreme would be to envisage watersheds and flooding as hyperobjects[23] similar to, for example, climate change – distributed in time and space, complex, hard to touch and define, but that we know exist because of the real phenomena they manifest. Such reasoning may then force us to a more encompassing, inclusive, eco-social awareness and a 'flood of approaches' through which we can apply a fuller range of modes of enquiry and understanding. For example, rather than seeking solely to avoid flooding, the use of managed levee breaches, redesigning, reducing or abandoning floodplain construction, lessening human vulnerability and improving pre- and post- flood healthcare, will better enable us to live with floods. The exact approach required will depend inevitably on the societal, cultural and historical attributes of a river basin, as well as its geomorphic characteristics, for example, narrow river valleys with limited floodplains versus lowland rivers and deltas with extensive floodplains. This mitigates against a one-size-fits-all approach to reducing vulnerability. In addition, as our ability to monitor floods and geomorphological change from satellites, and using big data (such as social media), becomes increasingly comprehensive and offers transformative advances, this must be accompanied by historically, socially and medically grounded studies that possess a common language across disciplines[24]. Incorporating the roles of sediment[4] and human agency[3] into these deliberations is essential to reducing the impact of flood hazards and subsequent disasters.

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